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TERTIARY AND RECENT GLACIATION OF AN ICELANDIC VALLEY

HENRY G. FERGUSON

During the summer of 1905 I had the opportunity of accompanying Dr. Helgi Pjetursson, the well-known Icelandic geologist, on his trip through the west and north of Iceland. Our primary purpose was the study of the sedimentary beds included between the lava flows of the Tertiary basalt plateau of the island. Dr. Pjetursson has made some remarkable discoveries concerning these sedimentary beds, the most interesting of which is the finding of glacial deposits—apparently indurated ground moraines—between the older lava flows. Dr. Pjetursson has already described these formations,[1] but as they are little known to American geologists, I propose to describe one of the areas where these beds are best developed, the Botnsdalr valley at the head of the Hvalfjord, about 30 miles northeast of Reykjavik.

The basalts forming the walls of the valley dip eastward at an angle from 5° to 10°, this eastward dip being constant for the whole western part of the island, except occasionally near the west coast, where the boundary faults of the island cause a westerly dip. These tilted basalts are called "regional" by Dr. Pjetursson, as being common to northern Scotland, the Orkneys, the Shetlands, the Faroes, Iceland, and western Greenland; in distinction from the "insular" basaltic lavas, peculiar to Iceland. These "regional" basalts are roughly divided into a lower or black group, which contains the "Surturbrandur" lignite and ash deposits, with Miocene plant remains; and the gray group, which, like the gray group of Ben More[1] in the Mull plateau, is the upper group in the Icelandic plateau. The latter is equally deformed, but is separated from the black by an erosional unconformity. The basalts of the Botnsdalr region seem to belong high up in the black group.

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[1] Helgi Pjetursson, "Om nogle glaciale og interglaciale Vulkaner paa Island," *Det kgl. Danske Videnskabernes Selskabs Forhandlinger*, No. 4, 1904.

Except for this erosional unconformity, there is no evidence, such as any large unconformity or discordance of dip, to indicate any marked

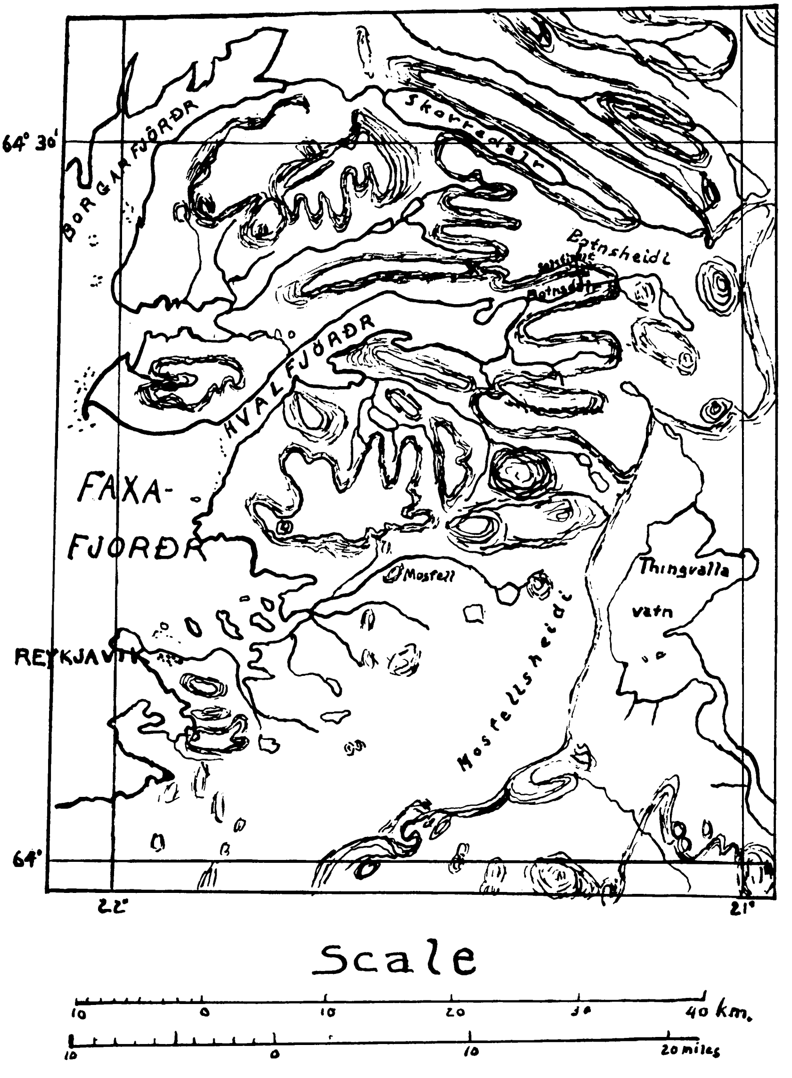

FIG. 1.—Hvalfjord and vicinity. From Thoroddsen's Map of Iceland, 1900.

pause in the volcanic activity which built up the plateau. After the building of the plateau, and before the later glacial periods, came the movements which tilted these older basalts, forming a synclinal trough across the center of the island, where the most active of the present volcanoes are now found. This seems to have been accompanied by a certain amount of subsidence, and the present top of the plateau is in reality an old peneplain surface, the truncated edges of the tilted lava flows reaching about the same level. In regions where the dip is steeper than in the Botnsdalr, this gives a very noticeable serrate appearance to the sky-line. Whether this peneplain is tilted through later movements cannot be ascertained until better topographic maps are available, but the surface is much broken by later faulting. During this period came the extensive faulting, which greatly reduced the size of the island, and later the erosion of the fiords, these in part due themselves to faults. After the island had assumed roughly its present shape came the flat-lying lavas noted on Thoroddsen's map as "Doleritic lava (pre-glacial and glacial)," and several glacial periods. The time required for the peneplanation of the plateau, its uplift, and the present erosion seems to furnish additional evidence that the regional basalts are Tertiary in age.

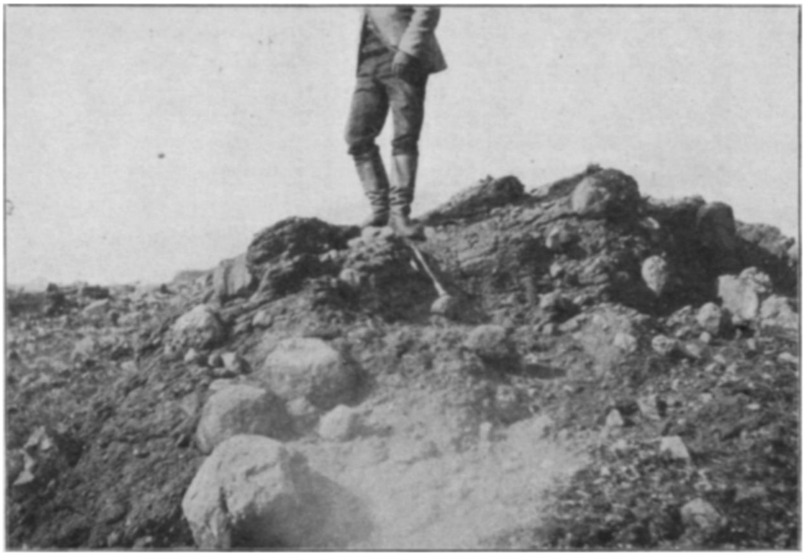

FIG. 2.—Indurated moraine on the south shore of the Hvalfjord.

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[1] A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, p. 215.

The Botnsdalr is a glacial valley, a continuation of the northern branch of the Hvalfjord, one of the east-west fiords of the Faxafjord. It is some 10 miles in length, east-northeasterly in direction, has a gentle grade from sea-level, and a width of a mile at its mouth, widening somewhat up-stream. The cliffs where the indurated ground-moraines occur rise very precipitously to a maximum elevation of some 1,200 feet, the lower 300 or 400 feet being largely masked by talus. As it was impossible to climb the cliff on the southern side of the valley, the section here described is on the northern cliff, known as the Selsfjall.

The indurated moraines[1] contain subangular pebbles and bowlders of all sizes up to 2 or 3 feet in diameter, which often show distinct striations. The cementing matrix is fine and sandy, all the grains showing some abrasion, differing in this from the

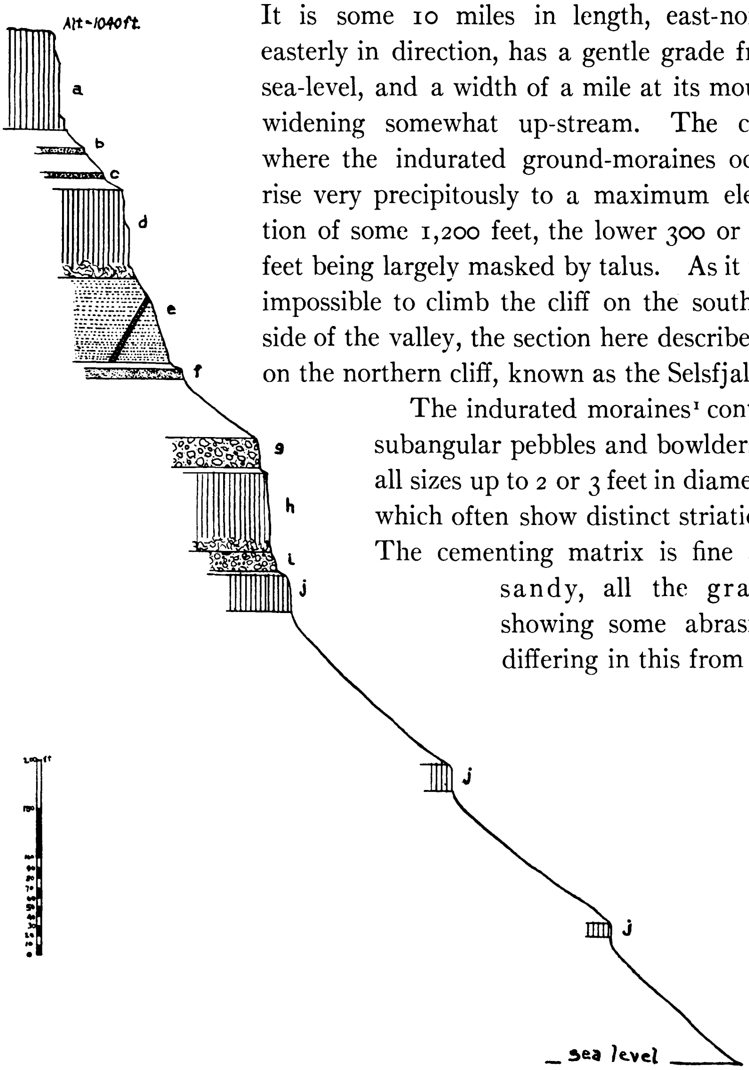

FIG. 3.—Main section on the Selsfjall.

a, basalt, several flows; *b*, flat-lying tuffaceous sandstone; *c*, third moraine; *d*, basalt, several flows; *e*, ripple-marked sandstone, cut by basalt dike; *f*, contorted tufaceous sandstone; *g*, second moraine; *h*, basalt, several flows; *i*, first moraine; *j*, basalt.

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[1] For a description of Quaternary indurated moraines in southern Iceland, see H. Pjetursson, "The Glacial Palagonite Formation of Iceland," *Scottish Geographical Magazine*, Vol. XVI (1900), No. 5.

volcanic agglomerates and breccias, which contain small angular bits of black glass or "palagonite." The material is absolutely unstratified, thus differing from the "jökullhlaup" sediments described below, which show more or less distinct bedding. Dr. von Knebel,[1] however, describes indurated "jökullhlaup" sediments of the southern part of Iceland in terms which would be equally applicable to the beds I here describe as moraines.

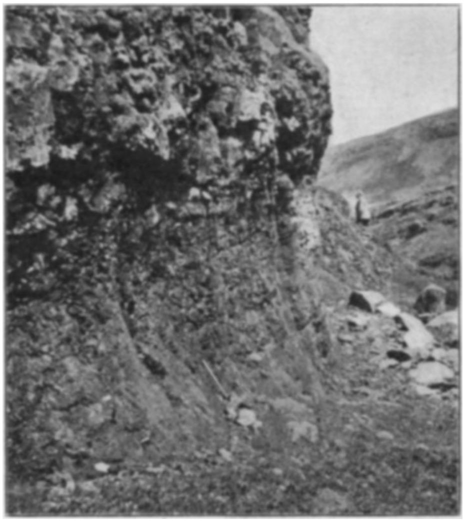

FIG. 4.—Lower moraine and overlying basalt.

The basalt flows, averaging about 25 feet in thickness, are almost invariably brecciated near the lower surface, strikingly columnar in the center, and vesicular near the top. Where immediately covered by another flow, the upper surface is ropy.

The section on the Selsfjall is best explained by the accompanying illustrations. In the main section (Fig. 3) it will be seen that there are three morainal beds, usually covered by sandstone, instead of being directly overlain by basalt.

The lower ground-moraine is about 20 feet thick, and has no overlying sandstone. In consequence of being directly overlain by the basalt, the upper 3 or 4 feet of the bed are so thoroughly baked that the pebbles break off even with the matrix.

The second moraine, at the point shown in the section, is almost hidden by the talus. A few feet above the moraine is a small outcrop of a much contorted tufaceous sandstone. This contortion seems inexplicable, except through the action of an advancing glacier, thus showing, with the earlier advance supplied by the ground moraine below it, a twofold advance and retreat of the ice during the period represented by this sedimentary series.

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[1] Dr. Walther von Knebel, "Vorläufige Mitteilung über die Lagerungsverhältnisse glazialer Bildungen auf Island etc.," *Centralblatt für Mineralogie Geologie und Paläontologie*, Jahrgang 1905, No. 17–18, p. 539. See also, H. Pjetursson, "Das Pleistocän Islands," *Centralblatt für Mineralogie, Geologie und Paläontologie*, Jahrgang 1905, No. 24.

Above the contorted tufaceous sandstone is almost 100 feet of flat-lying ripple-marked sandstone, alternating between layers of fine clay and sandstone, the latter often spotted with pebbles of vesicular basalt. The clay layers were generally about an inch in thickness, while the sandy layers were often a foot thick and seemed to represent the annual flood of the stream. The ripple marks, by the steeper slope of the ripple ridges, showed a southwesterly direction of flow. In one place the sandstone was cut by a basalt dike which probably served as a feeder to some of the upper lava flows.

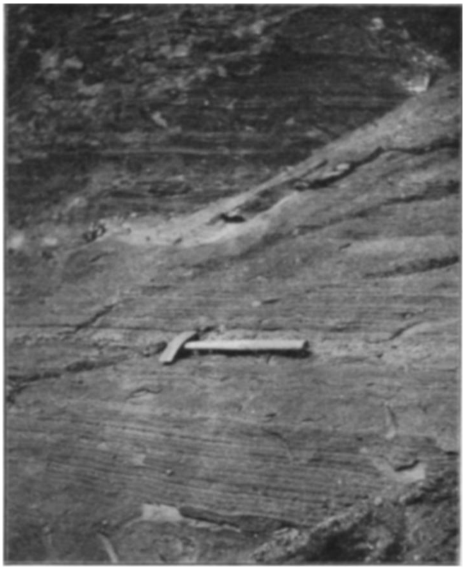

FIG. 5.—Ripple-marked sandstone above the second moraine.

The third moraine in this section did not exhibit any marked peculiarity. Like the second, it was overlain by tufaceous sandstone, in this case nearly flat-lying and not ripple-marked.

About 5 miles down the valley, to the westward from the main section, there is a good exposure of what is probably the second moraine of the first series. Here the overlying contorted sandstone is entirely lacking, and the sandstone above the moraine is more evenly bedded, shows no ripple marks, and is much more conglomeratic, containing several subangular bowlders, which at first sight gives it the appearance of morainal material.

Higher up on the cliff the third moraine is well exposed in a small gorge, and consists of about 10 feet of indurated moraine, containing some well-striated pebbles. It rests on basalt which has a polished surface, but is not distinctly striated. It is overlain by 20 feet of fine sandstone, which, in turn, is covered by extremely brecciated basalt.

Near this point at the top of the cliff, at an altitude of about 1,200 feet, remnants of a fourth indurated ground-moraine were found. A deep gorge prevented close examination of this bed, which differs slightly from the others. It rests directly on the truncated columns of a basalt flow, and seems to have sections of these same columns caught up in it, and but slightly rounded. The bowlders are larger than in any of the other ground-moraines, several being 3 feet in diameter. Where seen, it was not overlain by basalt; hence it is not necessarily Tertiary in age.

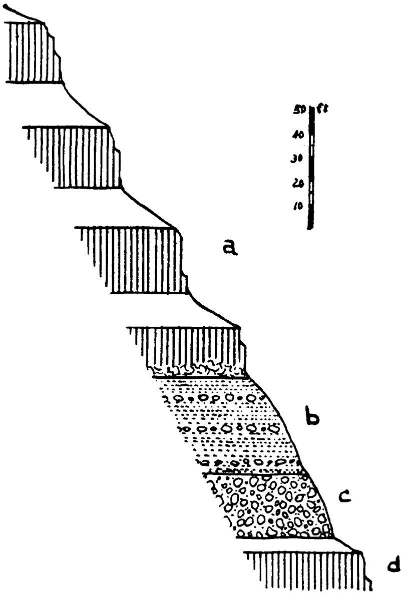

FIG. 6.—Second moraine, five miles to the west of main section

a, basalt, several flows; *b*, flat-lying sandstone and conglomerate; *c*, moraine; *d*, basalt.

Another, somewhat similar section appears on the face of the Botnselvens Klöft, a deep gorge entering the eastern end of the Botnsðalr on the northern side. The section is shown in Figure 8. It is impossible to attempt any definite correlation, but unless the beds have been disturbed by faulting, of which there is abundant evidence in the Skorradalr, a neighboring valley, the moraines here shown should correspond approximately to the third moraine of Fig. 3. The stratified material above the upper moraine appears to be overlain by basalt farther to the eastward. The two moraines have extremely uneven upper surfaces, as if there had been great irregularity in their upper surfaces as deposited, or as if they had undergone considerable erosion between the time of the retreat of the ice-sheet and the deposition of the sandstone and conglomerate above them. The upper surface of the basalt flow between the two moraines is distinctly striated adjacent to the moraine, the scratches often running under the moraine itself.

On the southern side of the valley one of the higher moraines is nearly horizontal, with the gently tilted basalt flows resting against it, as if the moraine had originally been deposited on a sloping surface and had been subsequently buried by overlapping lava flows. Later tilting has given the position shown in Fig. 9.

There are certain points of similarity in these different Tertiary morainal beds which are worth noting:

The indurated moraines are weaker members of the cliffs than are the basalts, and hence tend to form shelves and have their lower contacts, the critical points of such beds, covered by talus. Whenever the contact is visible, as in the two points mentioned above, and in several other localities in the vicinity of the Hvalfjord, it is smoothed or striated.

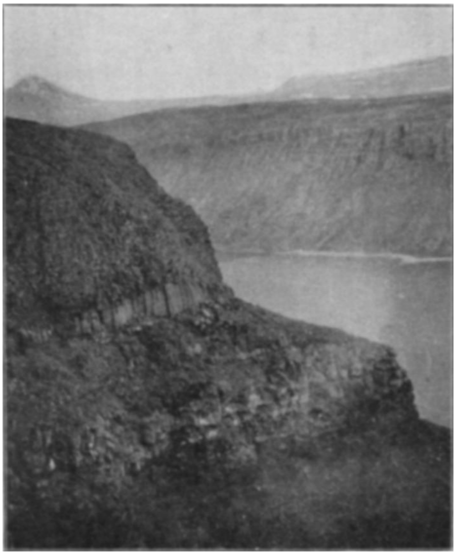

FIG. 7.—Sandstone above the second moraine.

In nearly every case the moraine is overlain by bedded material, as if from deposits laid down by glacial streams during a retreat of the ice-sheet. No delta beds, so common in our glacio-fluvatile deposits, were seen, but perhaps these might be found if the sedimentary beds of the basalt plateau were studied in greater detail.

The lower surfaces of the basalt flows lying above the sandstone seem much more brecciated than those which rest on other basalt flows. This brecciation may have been caused by explosions due to the presence of standing water when the lava was fluid.

The inconstant nature of the moraines and sandstones is very noticeable; the beds change greatly in size in a very short distance, and it is at present impossible to make any definite correlation between the sections.

The later glacial history of the Botnsdalr is illustrated by the following facts:

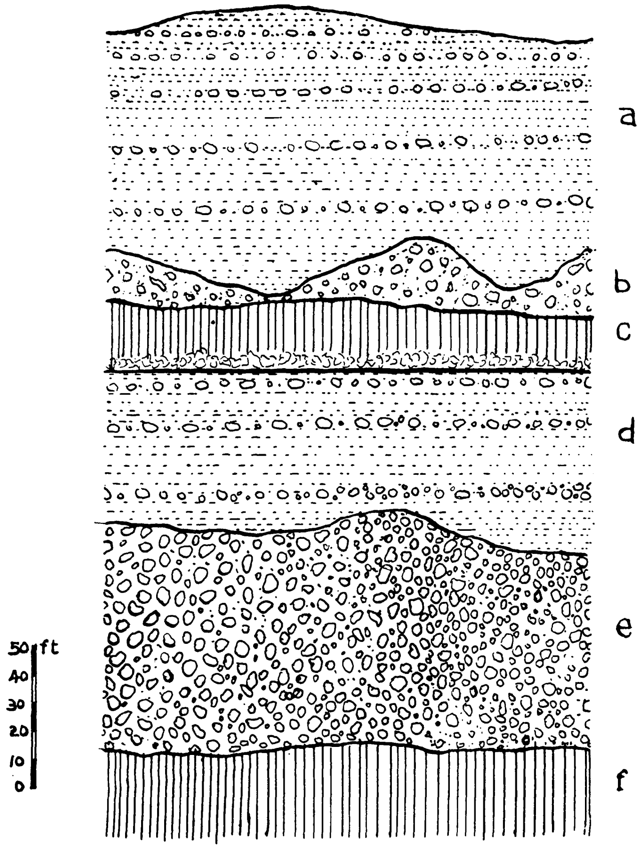

FIG. 8.—Section in Bothselvens Klöft.

a, sandstone and conglomerate; *b*, thin moraines; *c*, glaciated basalt, single flow; *d*, sandstone and conglomerate; *e*, large moraine; *f*, basalt.

In the eastern part of the valley, at a point where the cliffs are less prominent and the valley opens out considerably, is a glaciated hill, somewhat in the form of a *roche moutonnée*, composed chiefly of tuffs, breccias, and a little lava, indicating by their radial dips the ruins of a volcano, younger than the valley. These tuffs, bomb-breccias and lavas were capped by a few feet of indurated moraine, evidently inter-volcanic, as if it was even more thoroughly lithified than the indurated moraines in the Tertiary basalts. The pebbles were of vesicular basalt and, owing to their slaggy nature, did not show as good striations as the Tertiary moraines described above. The pebbles were all subangular, however, and a number showed striations.

A narrow gorge through this volcanic remnant showed an interesting section. The northern side was composed chiefly of tuff, volcanic breccias, and bomb-breccias, and thin lava flows, overlain by the indurated ground-moraine. These deposits rested on the older "regional" basalt, which showed distinct glacial striations, one rather faint set trending S. 15° W., the same direction as on the Botnsheidi, the plateau above the valley, showing the existence of an ice-sheet radiating outward from the center of the island; and the other more distinct trending S. 60° W., showing the action of a glacier following the present direction of the valley. The southern side of this hill has suffered most from recent glacial erosion, and here the indurated moraine seems to have been eroded off. Small pieces of a similar indurated moraine are found in the later terminal moraines at the mouth of the valley. The sedimentary beds, however, are different from those seen on the northern side of the hill. These are in part deposits, which Dr. Pjetursson believes to be due to a "jökullhlaup," literally "glacier-run," a flood caused by the sudden melting of vast quantities of ice, by a subglacial volcanic eruption. This material consists of very roughly stratified sandstone and conglomerate, of rapidly changing texture, varying from a hard clay, which, however, often contains subangular bowlders, to a coarse conglomerate. Often these beds show a faint and rather irregular cross-bedding. Large "scour and fill" unconformities are common, showing frequent changes in the stream-courses. At the point

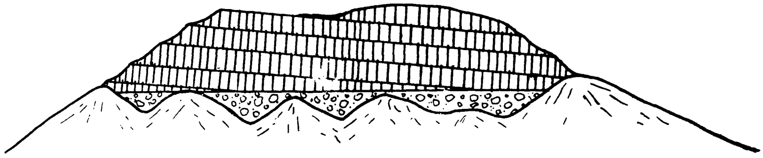

FIG. 9.—Contact of tilted basalts and upper moraine.

shown in Fig. 10 a stream-bed has been filled with an angular unstratified volcanic breccia. These sediments rest on glaciated "regional" basalt which shows the same double set of striations as before.

Later glaciation of the valley is shown by recent polishing of rock-ledges, the striations running parallel to the direction of the valley, and by three well-marked frontal moraines. The westermost of these, at an altitude of about 150 feet, forms a barrier across the valley, except where cut through by the present stream; the other two are merely remnants on the sides of the valley. At the northern end of the valley is a large delta, perhaps 150 feet above sea-level, somewhat over a mile in length, which marks the head of a body of water formed after the retreat of the last valley glacier. If this were a fresh-water lake, it is remarkable that its level remained constant long enough to allow such a large delta to be built, if the outlet stream was at a grade to enable it to do any effective down-cutting on the morainal barrier. The possible explanations seem to be either that, at the time of the formation of the delta, the sea stood at, or nearly at, the height of the top of the moraine, and that the gradual uplifting of the land allowed the stream to cut through the morainal dam and so drain the lake, or that the fiord itself formerly extended to the delta, and that the moraine was deposited in its shallow waters. These inferences are rendered more probable by the presence of old beaches and shell-beds at many places along the whole coast of Iceland, at elevations of from 50 to 300 feet above the present sea-level.

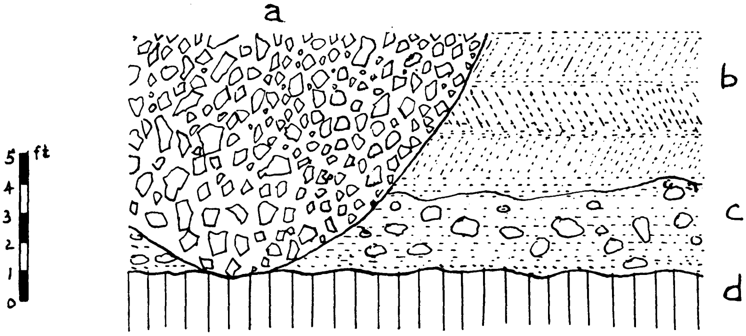

FIG. 10.—"Jökullhlaup" sediments and volcanic breccia.

a, volcanic breccia; *b*, roughly cross-bedded sandstone; *c*, conglomeratic sandstone; *d*, glaciated basalt.

To sum up the glacial history of the valley; it is evident that, during the formation of the Tertiary basaltic plateau, there were several advances of a glacier. This glaciation was probably local rather than continental, as the indurated ground-moraines are not a common feature of the plateau. After the break-up of the plateau—and the isolation of Iceland—by faulting—the evidence goes to show that the region was again glaciated by an ice-cap, moving radially outward from the center of the island. This is suggested by the directions of ice-movement, given by professor Thoroddsen in his geological map of Iceland,[1] and by the direction of striæ on the Botnsheidi and the faint striæ of S. 15° W. direction found on the basalt under the pleistocene volcano. The ice-cap gradually retreated and became broken up, the remnant, sending down glacier tongues which eroded out the valleys, as is the case today with the Vatna, Myrdals, Eyafjalla, Lang, Dranga, and other great ice-fields of the island. During the period of valley glaciation, and after the excavation of the valley, a small volcano, possibly contemporaneous with Mosfell, a pleistocene volcano, 20 miles to the southeast, broke out under the ice, causing sudden floods, which have left their characteristic deposits. The glacier, however, recovered what was lost by this melting, as is shown by the indurated moraine above the glacial volcano, and in one of its recent stages advanced to the shores of the Hvalfjord and there deposited its best-marked terminal moraine. On the last retreat of the ice, this moraine probably formed a dam holding back the waters of a glacial lake. The sea, being nearly at the top of the moraine, prevented the drainage of the lake, until the uplifting of the land allowed the stream to cut through the morainal barrier; or else the sea-water of the fiord itself followed the ice on its retreat and the delta was deposited at the head of a former extension of the Hvalfjord.

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[1] See also Th. Thoroddsen "Explorations in Iceland during the Years 1891–98," *Geographical Journal*, Vol. XIII (1899), No. 5, p. 493.